Center for Satellite and Hybrid Communication Networks

Modeling, Simulation and Performance Evaluation of Hybrid Networks

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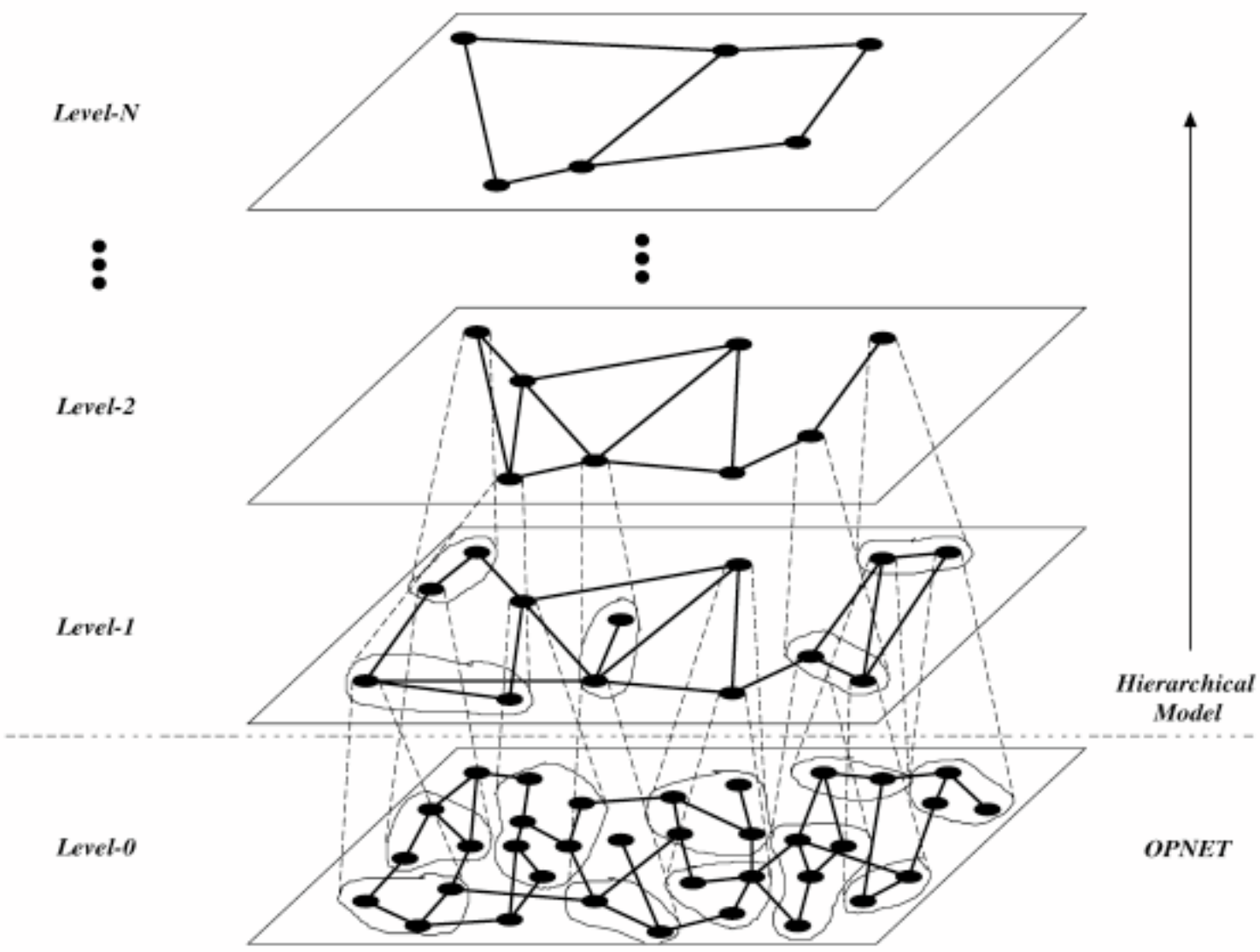
Objectives/Significance

- **Objectives**
  - Develop and demonstrate an Algorithmic and Software framework for Modeling and Performance Evaluation of large (e.g. 500,000 nodes) hybrid networks
  - Develop and demonstrate a versatile set of modules for modeling, simulation and performance evaluation of HDR satellite constellations
  - Develop trade-off analysis tools for evaluation of alternative hybrid network architectures
  - Develop efficient software architecture for modeling and simulation testbed operational through the Internet and World Wide Web
- **Significance**
  - Planning and Network Engineering Tools for broadband hybrid networks (including satellite constellations) nonexistent
  - Economic future of many commercial and military networks depends on careful trade-off in architecture, components, cost and performance

Approach

- Hierarchical algorithms based on network hierarchies
- Interactive tool to fit simplest possible traffic flow models at each level of the hierarchy (MMP, MMB, self-similar, etc.)
- Boundary (standardized) of a node (level 0) characterized by statistical models; obtained by discrete event simulation off-line
- Fast algorithms for progressive performance evaluation (layers cooperate)
- Mechanisms to summarize data/information exchange among layers
- Compute trade-off curves by linking hierarchical modeling system to multi-objective optimization packages (sensitivities)
- Performance metrics considered: Delay (also Delay variation, Maximum Delay), Throughput, Blocking probabilities (also Cell or Packet loss rate)

Hierarchical, Layered, Progressive Framework



Simulation Methodology

- Bottom-up approach
- Components modeled in precise detail and tested separately
- Integration at different levels
- The need to study hybrid and heterogeneous networks
  - Choose from various possible technologies.
  - Integration, tradeoffs and interoperability
- Need for a high level granularity study -- simulation
- Need for scalability study -- analytical approximation

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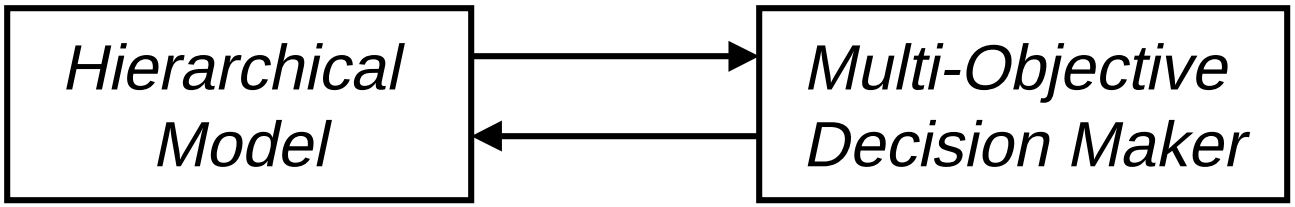
Analytical Model Framework

- Take simulation results as input
- Scale-up study with approximation models
- Tradeoff study and parameter tuning

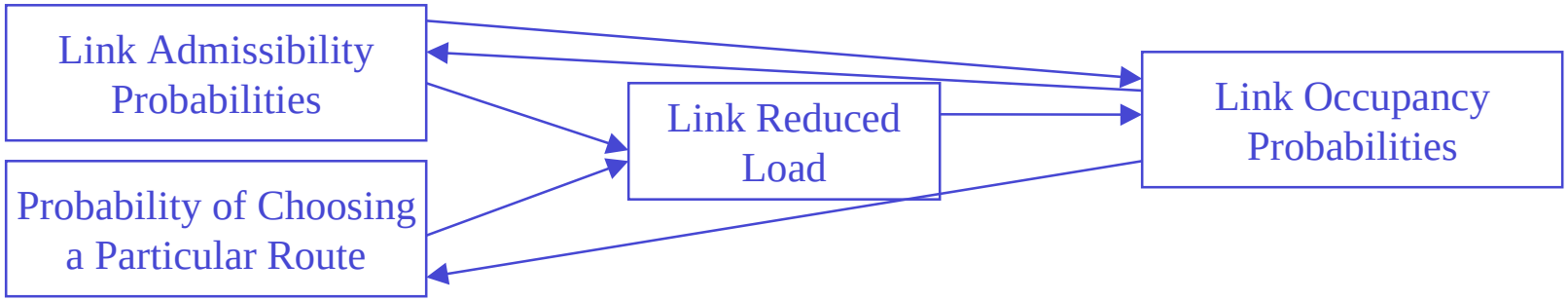


Approximations: Extensions and Applications

- **Extend analytical approximations**
  - Limitations of current approximations: direct routes, small number of hops; do not work with multiple classes of traffic
  - Do not cover mixed circuit-switched and packet-switched traffic
  - Need to cover packet-switched, multirate networks with different QoS traffic flows
- **Extended Reduced Load (Fixed-Point) method to cover adaptive routing scheme**
  - Maximal residual capacity adaptive routing (a MinMax scheme)
    - Define the most congested link on each available route
    - Choose the route that has the most free circuits on its most congested link
- **Initiated application to a commercial planned satellite constellation linked to terrestrial networks (systems engineering)**
- **Initiated application to a small subnetwork of a commercial satellite constellation; small subnetwork in OPNET; larger network via aggregation (systems engineering)**

Reduced Load Approximations: Extensions and Applications (cont.)

- **Method develops and approximates fixed points of the relationship between link arrival rates, link admission probabilities and routing decisions**
  - Network equilibrium, thus conservative performance estimates



- **Orders of magnitude faster than OPNET-based simulation**
- **Linked to multi-objective optimization for network dimensioning (capacity selection) and protocol or other parameter tuning**
  - Optimization based design and trade-off in networks
  - Design of trunk reservation parameter
  - Network resource allocation
- **Hierarchical extensions of the algorithms**
  - Based on physical network hierarchies
  - Based on statistical aggregation and model simplification at higher layers

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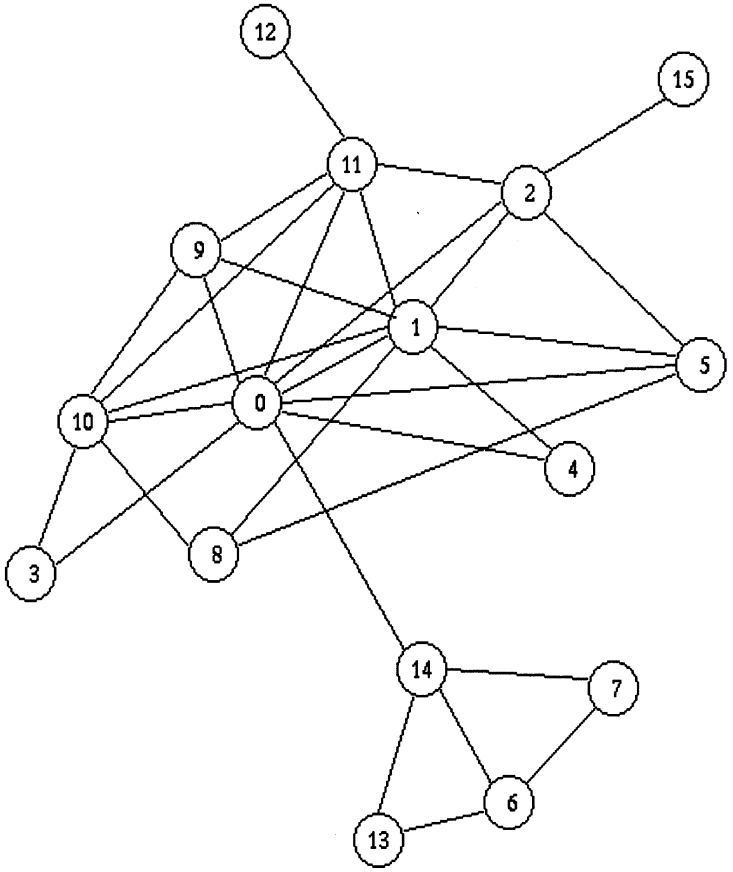
An Example

- **From an existing commercial network**
  - 16 nodes and 31 links; link capacity 60 to 180 trunks
  - Traffic of four types requiring bandwidth of 1,2,3,4 trunks
  - No admission control
- **Traffic metrics: end-to-end blocking probability; end-to-end throughput.**
- **Any origin-destination node pair has at most 7 alternate routes, any route has at most 5 hops.**
  - Several allowed routes
  - Call request --> compute admissible routes (enough free bandwidth)
  - Find most congested links (least free circuits)
  - Call routed on route with maximum number of free circuits
- **Simulation run to get 95% confidence interval**
- **Very accurate as compared to discrete-event simulation**
  - Better approximation under heavy traffic
  - 10 times faster than discrete event simulation (single layer)



Experiments, Simulation Results

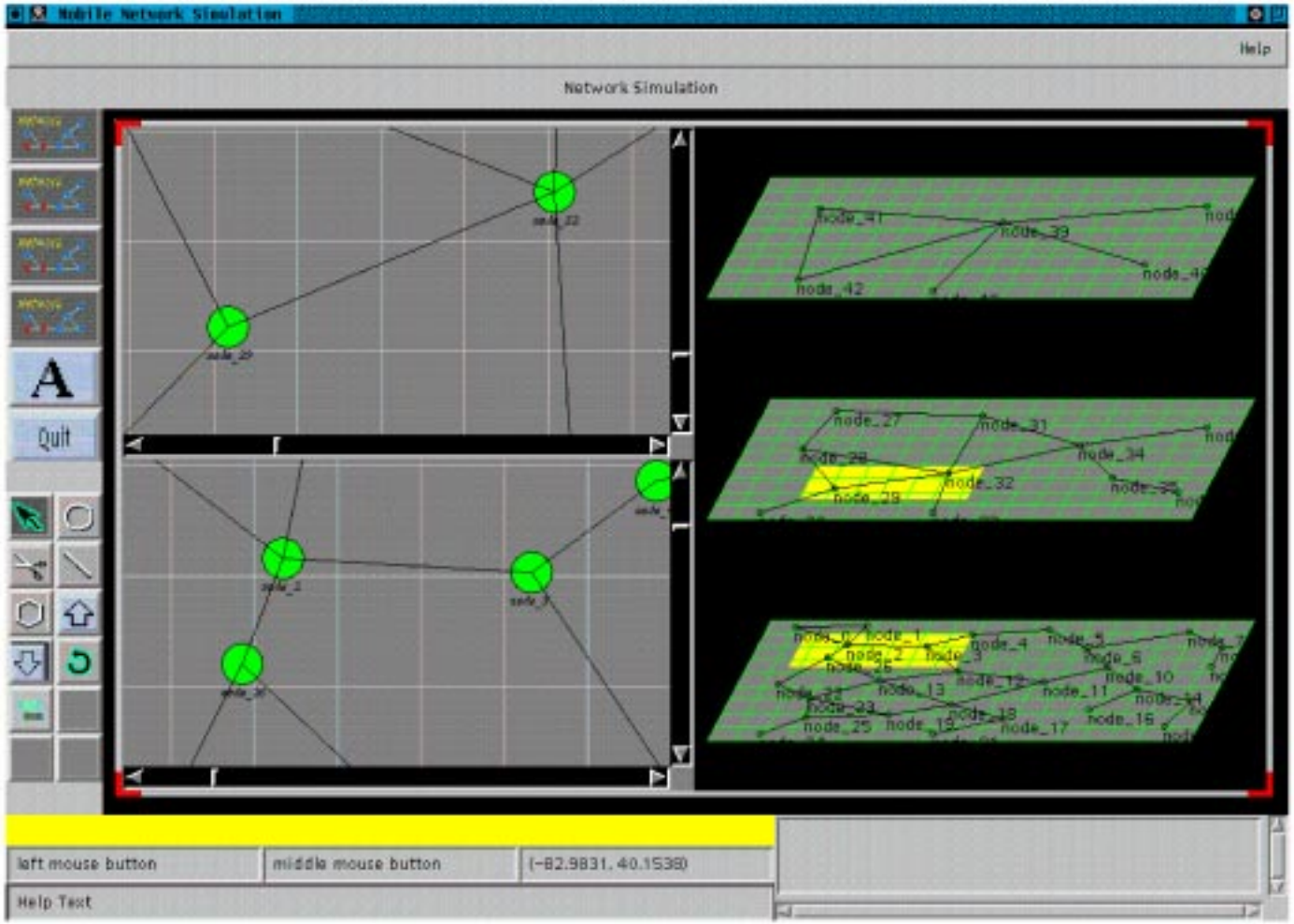
Node Pair	Class	Fixed Point Method	Discrete Event Simulation	Fixed Point Method	Discrete Event Simulation	Fixed Point Method	Discrete Event Simulation
(0, 4)	4	0.003234	(0.0, 0.0)	0.055354	(0.0512, 0.0549)	0.112658	(0.0025, 0.0026)
(0, 13)	1	0.036512	(0.0351, 0.0369)	0.107588	(0.0987, 0.1012)	0.135564	(0.1492, 0.1500)
(1, 6)	1	0.036999	(0.0303, 0.0311)	0.117211	(0.1113, 0.1121)	0.156322	(0.1445, 0.1466)
(5, 6)	3	0.114667	(0.1103, 0.1137)	0.332202	(0.3137, 0.3142)	0.419781	(0.3922, 0.3940)
(6, 10)	2	0.073531	(0.0543, 0.0573)	0.212533	(0.2164, 0.2210)	0.269145	(0.2572, 0.2583)
(9, 13)	4	0.164185	(0.1213, 0.1268)	0.424501	(0.3380, 0.3465)	0.519083	(0.4791, 0.4793)
Number of Iterations		23		24		24	
CPU Time (seconds)		120.35	3.9×10^4	125.55	5.6×10^4	125.11	2.3×10^6

1.2 Nominal Traffic **1.6 Nominal Traffic** **1.8 Nominal Traffic**

Software Architecture Developed

- **Client/Server based architecture**
  - simulation kernel - - hosted at server; browser-based GUI - - client
- **Java, CORBA**
  - CORBA: distributed object computing with object invocations executed in "server"
  - JAVA: object invocations executed in "client"
- **Object structure:** nodes and channels
  - Server node objects: contain data that must be persistent from run to run
  - Client node objects: decorated versions of server objects with additional GUI functions
  - Client channel objects: capture spatial, topological and qualitative characteristics
  - Server channel objects: translated into math. quantities of the model
- **Software architecture uses "composition" pattern**
- **GUI accessible via WWW browser**

JAVA GUI to Hierarchical Performance Evaluation Tool



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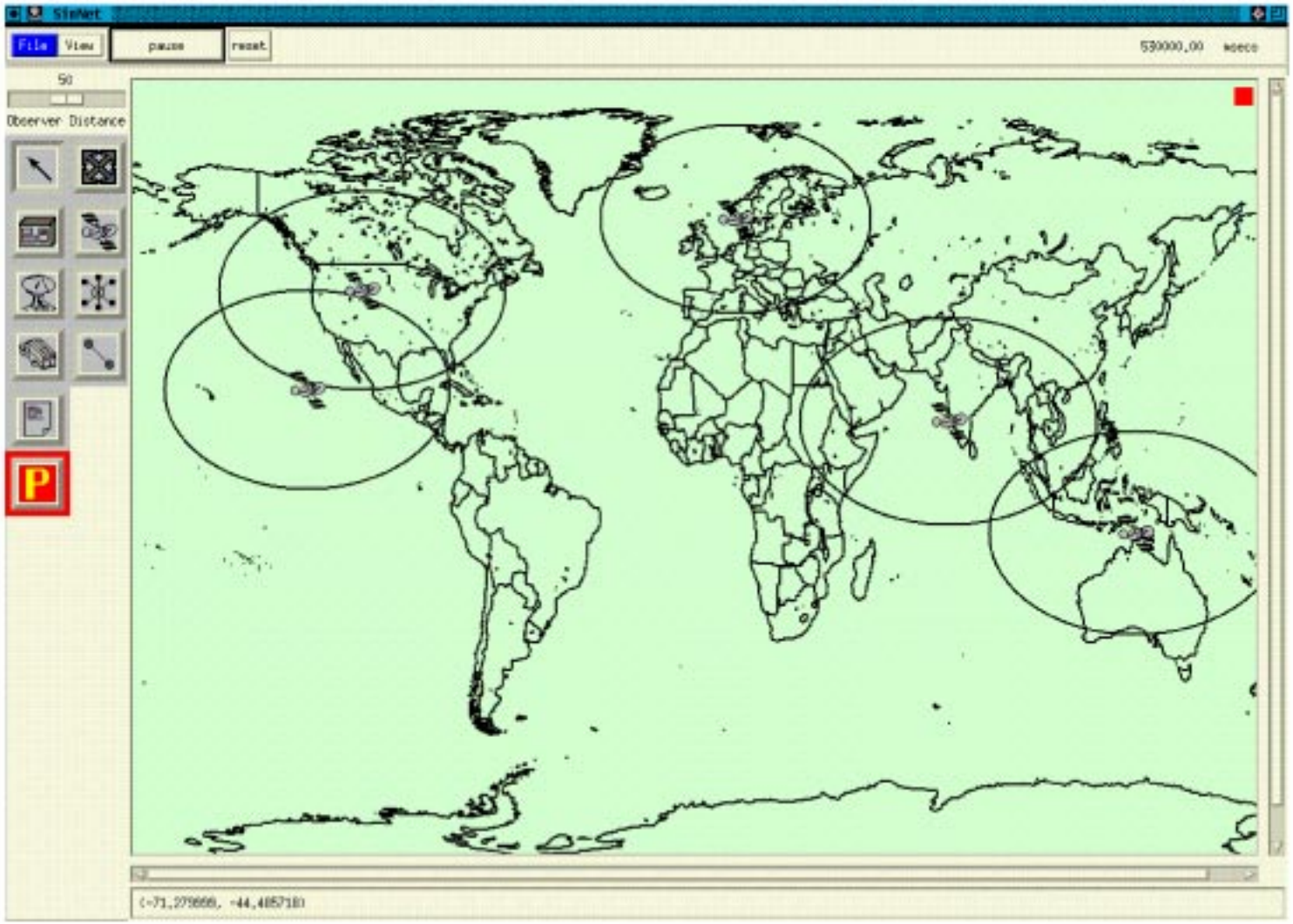

CSHCN Internet over Satellite Simulation Testbed

- **Completed First Phase of Internet simulation testbed OPNET-based**
  - TCP Reno, Tahoe
  - TCP SACK and FACK
  - RED, FRED Queue Management
  - TCP Spoofing/Connection Splitting
  - Hybrid Internet (entire system)
  - Timestamps
  - TCP scaled window option
  - MMPP/MMBP traffic model; Self-similar traffic generator
  - Classical IP over ATM with the gateway

Current Work

- Complete object models for a satellite constellation
- Complete satellite object model
- Complete link models for a satellite constellation
- Complete mathematics of approximations
- Complete automatic generation of OPNET modules and parameter generation
- Complete OPNET system software interface
- Complete performance graphics
- Demonstrate system as a tool for architecture selection
- Demonstrate system as a tool for trade-off analysis (cost vs QoS achieved)